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NIF and OMEGA X-Ray Environments Summary

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The National Ignition Facility (NIF) is a 192-beam laser system at Lawrence Livermore National Laboratory in California. The facility can deliver up to 1.8 MJ of ultraviolet energy to a target in shaped pulses that range from 1 – 20 ns in duration.^{1,2} The facility offers a 10 m diameter target chamber at high vacuum (10^{-5} – 10^{-4} torr) in which objects under test can be located.³ There are three diagnostic instrument manipulators (DIMs) that can be used for precise positioning of test objects or quick service and refurbishment of diagnostic systems.^{4,5} The facility plans to add two more DIMs by the end of calendar year 2016. The NIF currently pursues research into inertially confined fusion processes⁶, high-energy-density science for the U.S. stockpile stewardship program⁷, fundamental science research⁸, and other national security applications such as radiation effects on materials, devices and systems,⁹ and weapons effects phenomena¹⁰ as well as issues relating to counter nuclear terrorism¹¹.

The facility can produce substantial neutron pulses (currently up to 10^{16} neutrons with a narrow 14-MeV energy spectrum in a pulse several 10's of ps wide) and substantial x-ray fluxes and fluences.^{12, 13, 14, 15, 16} The limiting parameter on the x-ray fluence delivered to a test object is the stand-off distance between the test object and the x-ray source. The test object must be positioned so that it avoids blocking the laser beams used to create the x-ray source. Currently, we have designed test cassettes that place a 1.5" diameter sample as close as 10 cm from target chamber center. The largest diameter of any test object to be positioned with a DIM must be less than 30 cm. Table 1 lists some of the x-ray sources used in x-ray effects testing that have been designed and/or verified to date. Research is underway to continually improve the performance of these and new x-ray sources. Note that nearly all the sources in Table 1 have been investigated with ≈ 700 kJ or less of laser drive; higher-energy drives are possible.

Source	Yield (kJ/sr)	Energy band (keV)	Pulse width (ns)	10-90% Rise	notes
Ar:Xe gas ¹²	8.4 ± 0.8 16.8 ± 2.4	3 – 7 < 3	3 and 5 ns ramped.	2.0 ns for ramped	3 and 5 ns sources demonstrated with 0.35 and 0.7 MJ of drive.
Kr:Xe gas ¹³	4.9 ± 0.24 38.4 ± 5.8	3.5 – 7 < 3	14 ns flat	4 - 5 ns	14 ns source demonstrated with 1.34 MJ of drive. (< 3 keV emission from N131004)
SS304 cavity ¹⁴	2.5 ± 0.13	5 – 9	4 ns fwhm ramped	2.0 ns	Demonstrated with 0.5 and 0.7 MJ of drive (dominated by 6.7 keV)
Cu foam	1.6 ± 0.47	7.5 – 9.5	4 ns fwhm ramped	2.0 ns	Demonstrated with 0.5 MJ of drive (dominated by 8.3 keV)
Kr gas ¹⁵	1.6 ± 0.1	> 9	3 and 5 ns ramped	1.5 ns	Demonstrated with 0.75 MJ of drive (dominated by 13 keV)
Mo cavity ¹⁶	0.7 ± 0.3	17-20	2 ns fwhm ramped	1.7 ns	Demonstrated with 1 MJ of drive (dominated by 18 keV)

Table 1 – Measured x-ray outputs from a variety of targets shot at the NIF. The columns are the source description (gas, foam, metal-lined cavity), the measured x-ray yield and uncertainty due to diagnostic accuracy and statistical reproducibility, the energy band over which the measurements are made, the pulse width (full width at half maximum for ramped x-ray waveforms) of the x-ray flux, the 10-90% rise time of the leading edge of the x-ray waveform, and finally some notes. Much greater detail can be found in Refs. 12 – 16.

The OMEGA laser system is a 60-beam system operated by the Laboratory for Laser Energetics at the University of Rochester, in Rochester NY. The OMEGA beams can deliver up to 30 kJ of energy in pulses ranging from 1 to 5 ns, with flexible pulse shaping capability.¹⁷ Unlike the NIF, where the laser beams come from the upper and lower hemispheres of the target chamber in four sets of cones, the 60 OMEGA beams come from all angles on the spherical target chamber. This is because the OMEGA laser pursues direct drive fusion research¹⁸, and uses the lasers directly to compress the fuel capsule. This sometimes limits the number of beams that can be used to create a plasma radiation source. The OMEGA chamber is 3 m in diameter and has six Ten Inch Manipulators (TIMs) positioned around it at different polar and azimuthal angles. The TIMs offer very easy access for modifications and refurbishments to diagnostic systems and are easily modified to (temporarily) enhance data acquisition capability¹⁹, which has been done in the past to support radiation effects testing²⁰, optics testing^{21, 22} and solar cell survivability tests²³. Table 2 summarizes some of the multi-keV x-ray sources that have been developed and used for radiation-effects testing at OMEGA. The details of the spectral content, x-ray waveforms and other source characteristics are published for: Ar K-shell²⁴, Xe L-shell²⁵, Ti K-shell²⁶, Fe aerogel and SS304 cavity K-shell²⁷, Cu foam K-shell, Ge aerogel K-shell²⁸ and Kr gas K-shell emission²⁹.

Source	Yield (J/sr)	Energy band (keV)	Pulse width (ns)	10-90% Rise	notes
Ar gas ²⁴	55.6 ± 14.3 64.7 ± 24.3	3 – 3.6 2 – 5.5	2	1.2	Unpublished from 2010 APS poster
Xe gas ²⁵	200 ± 40	4 - 7	1.5		20 kJ at 2x10 ¹⁵ W/cm ² at OMEGA
Ti aerogel ²⁶	84 ± 8	4.6 – 6.0	1.2	0.8	Optimum yield at 1x10 ¹⁵ W/cm ² (K-shell dominated by 4.7 keV)
	970 ± 70	0 – 20	1.5	1.0	
Fe aerogel ²⁷	35 ± 15	6.5 – 8.5	1.2	0.8	Optimum yield at 1-2x10 ¹⁵ W/cm ² (K-shell dominated by 6.7 keV)
	800 ± 80	0 – 20	1.5	--	
SS304 cavity ²⁷	30 ± 5	6.5 – 8.5	≈2.5	0.8	Emission shows late-time enhancement (K-shell dominated by 6.7 keV)
	1200 ± 120	0 - 20	≈3.0	--	
Cu foam	27 ± 7.5	4 – 9.5	1	0.8	Preliminary analysis of data taken in November 2014.
Ge aerogel ²⁸	11 ± 2	> 9	1.0	0.8	Optimum yield at 2x10 ¹⁵ W/cm ² (K-shell dominated by 10.3 keV)
	700 ± 175	< 3.5	1.3	1.0	
Kr gas ²⁹	4.7 ± 1.6	> 12	< 1	< 1	Optimum yield at 2x10 ¹⁵ W/cm ² (K-shell dominated by 13 keV)
	527 ± 100	1.6 – 3.5	> 1	≈1	

Table 2 – Measured x-ray outputs from a variety of targets shot at OMEGA. The columns are the source description (gas, foam, metal-lined cavity), the measured x-ray yield and uncertainty due to diagnostic accuracy and statistical reproducibility, the energy band over which the measurements are made, the pulse width (full width at half maximum for Gaussian x-ray waveforms) of the x-ray flux, the 10-90% rise time of the leading edge of the x-ray waveform, and finally some notes.

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